PROGRESS OF LINEAR INJECTOR FOR SSC AT HIRFL*

Yuan He#, Zhijun Wang, Chen Xiao, Xiaonan Du, Zhouli Zhang, Liepeng Sun, Yaqing Yang, Xiaohu Zhang, Youjin Yuan, Institute of Modern Physics of Chinese Academy of Sciences, Lanzhou, China
Jing Wang, Lanzhou University of Technology, Lanzhou, China
Yuanrong Lu, Ge Liu, Shuli Gao, Kun Zhu, Jiaer Chen, Peking University, Beijing , China.

Abstract

A heavy ion linear accelerator for Separate Sector Cyclotron (SSC) is constructing at Heavy Ion Research Facility at Lanzhou (HIRFL). It is a new injector for SSC to improve its output beam intensity of 2 times for Super Heavy Experiment (SHE) and 10 times for injection of Cooling Storage Ring (CSR) than old Cyclotron. It has a normal conducting linac at upstream of SSC and one superconducting cryomodule at downstream of SSC to shift beam energy. The designed current of the linac is 0.5 mA and output energy is 0.576 MeV/u and 1.025 MeV/u. Beam dynamic study and prototype fabrication are introduced in the paper.

INTRODUCTION

Heavy Ion Research Facility at Lanzhou (HIRFL) consists of four accelerators, a Sector Focusing Cyclotron (SFC), a Separator Sector Cyclotron (SSC), a cooling storage synchrotron (CSRm), and a cooling storage ring for experimental (CSRe). SFC and SSC started running in 1998. CSRm and CSRe started running in 2008 [1]. The four accelerators are in series. SFC is the injector of SSC. SFC can be an injector of CSR for light ions. SFC and SSC work together to be the injector of CSR for heavy ions. That cause low efficient beam time of the whole facility.

Table 1: Specifications of SSC in two modes [2].

Parameters	Mode1	Mode2
Ions	$^{48}Ca^{7+}$ $^{56}Fe^{8+}$ $^{59}Ni^{9+}$ $^{70}Zn^{10+}$	$^{86}Ke^{14+}$ $^{136}Xe^{22+}$ $^{208}Pb^{33+}$ $^{238}U^{37+}$
A/q	~7	~6.4
Input energy (MeV/u)	0.576	1.025
RF frequency (MHz)	13.417	13.417
Harmonic Number	8	6
Output energy (MeV/u)	5.97	10.65
Acceptance		
x (π.mm.mrad)	13.0	16.4
Phase width (deg)	±12	±7
Energy spread (%)	±0.8	±0.8
Purpose	SHE	CSR injection

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#hey@impcas.ac.cn

A new linear injector for SSC, named SSC-LINAC, is being considered to improve the performance of HIRFL [3]. To reduce cost and complication, it will be a fixed frequency linac. The frequency is 53.667 MHz, four times of RF of SSC. SSC-LINAC can perform two special tasks, one is to supply middle mass ions, such as Ca, Fe, Ni, etc., for Super Heavy Elements (SHE) experiment, and the other is to inject heavy ions, such as U, Bi, Pb, etc., into CSR. Some specifications of two modes of SSC are listed in Table 1.

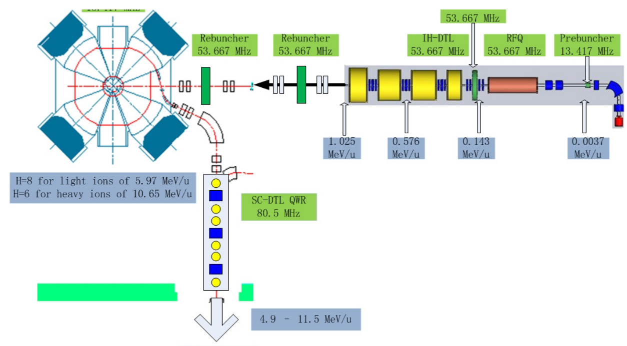

Figure 1: Concept of SSC-LINAC.

Table 2: Major Specifications of SSC-LINAC.

Parameters	Quantity	Unit
Beam frequency	13.417	MHz
Cavity frequency	53.667	MHz
A/q	<= 7	
Voltage of ion source	26.1	kV
Initial emittance (Norm.)	0.6	π.mm.mrad
Extraction energy of IS	3.728	keV/u
Output energy of RFQ	0.143	MeV/u
Output energy of Tank1	0.296	MeV/u
Output energy of Tank2	0.580	MeV/u
Output energy of Tank3	0.754	MeV/u
Output energy of Tank4	1.025	MeV/u
Duty factor	100%	

SSC-LINAC's concept is shown in figure 1. It is a normal conducting linac, including ECR ion source, LEBT with a prebuncher, one RFQ, MEBT with a rebuncher and four IH DTL tanks. Between Linac and

SSC, two normal conducting rebunches are employed to match in longitudinal. A cryomodule with 6 superconducting quarter wave resonators (QWR) of 80.5 MHz and 3 superconducting solenoids are employed to change beam energy with ±2.1 MeV/u after SSC. The beam energy after superconducting linac is from 4.9 MeV/u to 11.5 MeV/u. It is designed to match the two modes of SSC in Table 1. The major specifications of SSC-LINAC are listed in Table 2.

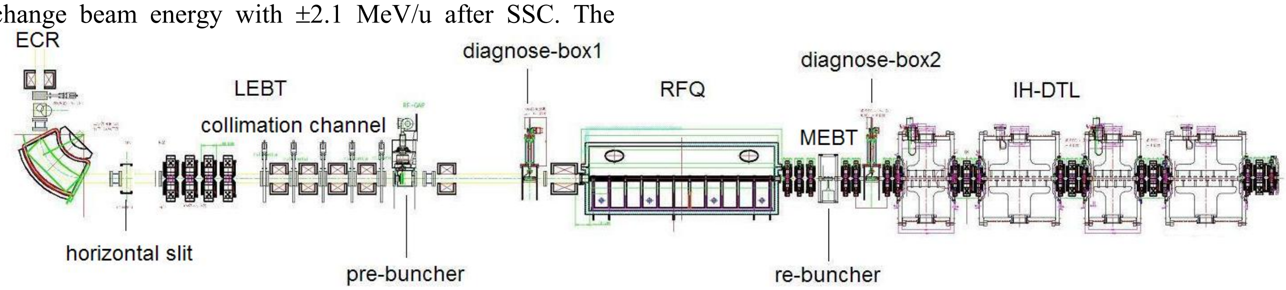

Figure 2: Layout of SSC-LINAC.

BEAM DYNAMICS

Figure 2 shows the layout of SSC-LINAC. Some special consideration was taken into account when the lattice was designed.

Figure 3: End to end simulation of SSC-LINAC.

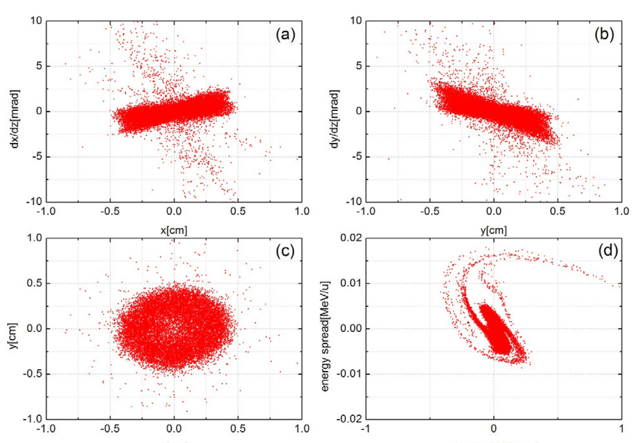

Figure 4: Particle distribution at the exit.

Collimations

Considering the small acceptance of SSC, the collimation channel with four solenoids and 5 collimators are employed after analysis dipole in LEBT. It is used to control transversal emittance into a small value, for instance 100 π.mm.mrad. The unwanted particles will loss on the collimator with very low energy.

Pre-buncher

The pre-buncher with 13.417 MHz is employed to bunch the beam previously to match the RF frequency of SSC. It is non-harmonic amplifier with more than 80% effective linear rising edge. In the simulation code, a four harmonic buncher is used instead.

Zero synchronous phase acceleration

To match the energy of SSC mode 1, the energy of 0.576 MeV/u is essential for the second tank. To control the gap voltage in tank1 and tank2 into a safe margin, the zero synchronous phases are used. The rebuncher with -90 degree synchronous phase is used to focus beam in longitudinal, and 8 zero-phase gaps in tank1 are following. The last two gaps in tank1 use -45 degree phase to turn the beam into a low-energy-spread condition. The first 3 gaps in tank 2 is -20 degree to focus beam and the other 8 gaps is 0 degree to get high acceleration efficiency.

A simulation from ion source to the exit of tank4 has been done by using track code. The results are shown in figure 3. The 4-rms emmitance at the entrance of LEBT is 0.2 π.mm.mrad assumed. Total transmission efficiency is 98.85% and the beam matched in the acceptance of SSC is around 74%. The 4-rms emittances are 0.237 and 0.266 π.mm.mrad separately in transversal and 1.085 keV/u.ns in longitudinal.

DESIGN OF HARDWARE

The prototypes and models of key hardware of SSC-LINAC have finished design and are under constructing. The LEBT is going to be commissioning from the beginning of 2012, and the RFQ and DTL tank1 are going to be commissioning from the Oct. 2012.

RFQ

The RFQ is a 4-rod type, 900 mm of diameter and 2600 mm of length. The power consumption is around 33 kW. The cavity is made of black steel with copper coating. The stems and electrodes are made of oxygen free copper. The cross section structure is shown in figure 5. Cooling channel goes through every stem and electrode and the supporting board is cooled separately. The end plates and cavity are water-cooled by copper pipes welded on the walls.

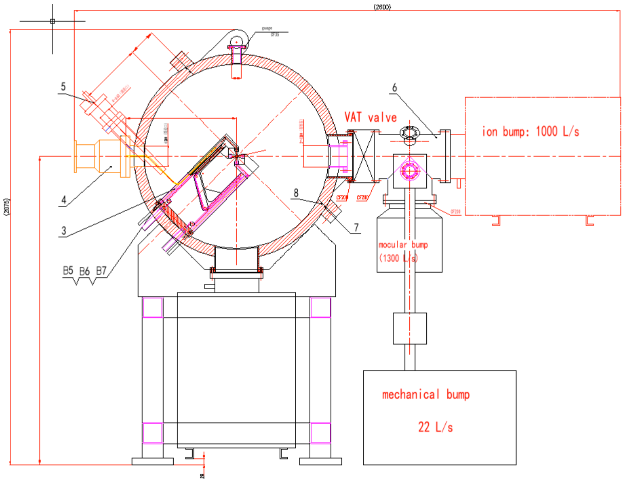

Figure 5: Cross section of RFQ.

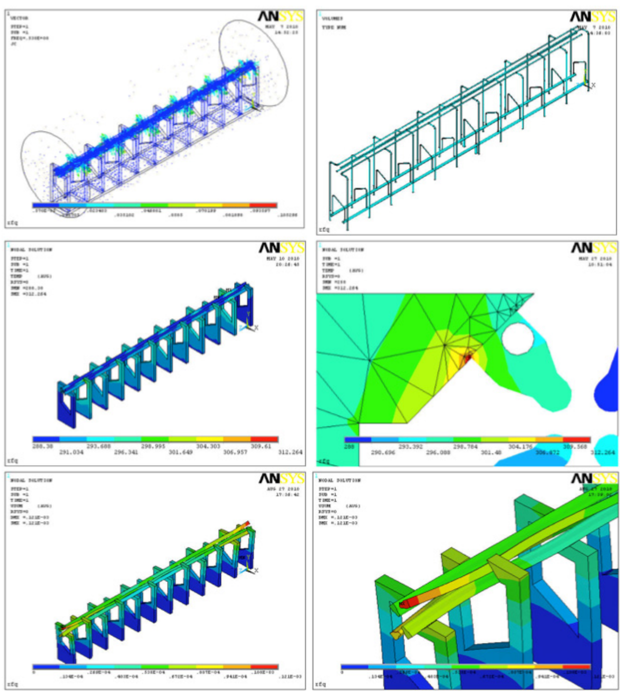

Figure 6: Multi-physics analysis of RFQ.

The RF-thermal-structure coupling analysis has been done by employing ANSYS code. It is assumed that the water and room temperature is assumed as 288 K, the speed of water is 2.5 m/s, the power consumption is 33 kW. The simulation model and results are shown in the figure 6. The maximum temperature rising is 30K, appearing at the conjunction between electrodes and stems. The maximum displacement is 0.12 mm, appearing at the end of electrodes. The frequency shift is 85 kHz caused by thermal deformation.

IH-DTL

The DTL's cavities are made of black steel with copper coating as well. The T-boards, stems, and drift tubes are made of oxygen free copper. Figure 7 shows the structure of DTL tank1. Before the final dimension to be fixed, the black steel cavity without coating, dummy T-boards and drift tubes made of aluminium were assembled together to tune frequency and field distribution. The measurement result agrees with simulation very well.

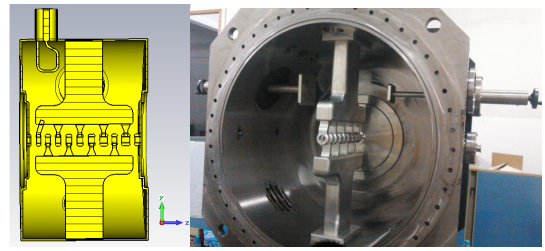

Figure 7: Structure of DTL Tank1.

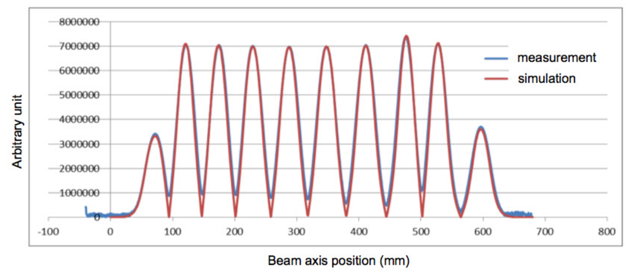

Figure 8: Structure of DTL Tank1.

Re-buncher

The re-buncher is a spiral drift tube resonator. The structure is shown in figure 9. An aluminum model has been fabricated and tested. The value of R/Q of measurement is 570, and simulation is 546. The field distribution agrees with each other between simulation and measurement.

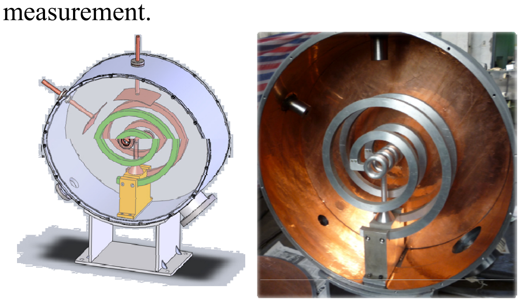

Figure 9: Structure of re-buncher.

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